EYE-MOVEMENTS DURING SEARCH FOR CODED AND UNCODED TARGETS

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SUMMARY PAGE

THE PROBLEM

To study the scanning behavior of observers searching for a target-dial in an array of dials which simulated a panel of dials on submarines. The dials were either uncoded or coded in various ways. To see if there is a relationship between speed of finding a target-dial and type of coding; between search-time and various measures of eye-movements; to determine if observers have a characteristic method of scanning and if certain methods of scanning are more efficient than others.

FINDINGS

Coding target-dials improves efficiency of performance, largely by reducing the number of necessary fixations. Subjects did not generally exhibit a characteristic scanpath and there was no indication that one method of scanning was reliably better than another.

APPLICATION

These results indicate which forms of coding are superior for improving efficiency of search through an array of dials.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit M4305.08-3001DAC9. The present report is Number 10 on this work unit. It was submitted for review on 18 June, approved for publication on 28 June 1974 and designated as NavSubMedRschLab Report No. 787.

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ABSTRACT

Eye-movements and search-time of four subjects were studied as they searched for a target-dial in a 4 x 4 array of dials which were differentiated either by (1) color, (2) shape, (3) a combination of color and shape, or (4) were uncoded. Search-time varied reliably between conditions: it was generally shortest in the color-condition, followed by color-shape, shape, and the uncoded condition. Subjects were capable of using both shape and color simultaneously. There was no difference in ratios of increase of search-time for color and shape as the target was situated more peripherally, and there was evidence that shapes, if properly chosen, might be as effective a coding device as color. Search-time was strongly associated with the average number of fixations required for target-detection but not with other measures of eye-movements. Subjects did not exhibit a reliable or characteristic scanpath, and method of scanning did not relate to search-time.

EYE-MOVEMENTS DURING SEARCH FOR CODED AND UNCODED TARGETS

INTRODUCTION

Modern submarines contain large and complex panels of meters and dials which must be extensively monitored to maintain the operation and safety of the ship. Little is known of the way in which different individuals actually carry out this task. Vigilance studies have shown that there are individual differences in target-detection and that performance often deteriorates with time.[1-4]

It has also been reported that a given individual will show a reliable pattern of eye-movements under different viewing conditions.[5] Gould and Peeples[6] reported that each subject generally uses the same scanning pattern throughout an experiment. But it is not clear if differences in performance are related to differences in visual search patterns.

If there is such a relationship, it raises several questions. Can individuals with poor scanning patterns be trained to make better scans? The little work that has been done on this problem has led several investigators to conclude that scan-paths are not very amenable to training.[7,8] Studies on reading ability have led to the conclusion that training in eye-movements does not improve reading skill.[9] Nevertheless, perhaps knowledge of an individual's scanning behavior could be used as a screening device for assigning him to the type of monitoring task to which he is best suited.

A second set of questions is concerned with the effects of the stimulus variables. Monitoring behavior is altered when the targets are coded in different ways. The study of eye-movements may prove useful in the design of equipment to maximize monitoring efficiency. Little is known, for example, about how the character of the non-target stimuli affects the search for the target. There have been a number of studies which have investigated search-time as a function of the amount of information available or the amount of irrelevant information, but only Williams[10,11] appears to have studied fixation errors with coded stimult; that is, if the subject is looking for a blue target, are certain colors looked at more often than others?

The purposes of the study, then, were to investigate the effects of coding dials by color, shape, and a combination of the two (1) on efficiency in finding a target-dial, and (2) on various measures of eye-movements. We also sought to determine if subjects have a reliable pattern of scanning under a given set of conditions, whether the pattern remains stable when the conditions are changed, and if there is a relationship between pattern of s scanning and the time needed to find a target-dial.

Apparatus

The subject sat behind a shutter with his head in a chin-rest 60 cm from a panel of 16 white dials arranged in a 4x4 rectangular array. Each dial subtended 6.2° visual angle in width and 5.7° in height. The vertical separation of the dials was 3.75°; the horizontal separation was 12°. The entire array subtended about 60 x 34°. The dials were set in a dark green background which subtended 64 x 44°. In the center of the array was a red light of .95° diameter which was the only thing visible through a small aperture in the shutter.* Ambient illumination was provided by fluorescent ceiling lights.

To color-code the dials, a sheet of white cardboard with 16 cut-outs for the dials and one for the red light was positioned over the entire panel. This could easily be slipped into place since the dials protruded about 1.5 cm from the background. Each cut-out was outlined with a 1.2° band of either blue, red, gree, or yellow (see Table I for color specifications). Each color appeared randomly in four locations on the sheet. Sixteen different sheets were constructed. During the experiment, the sheets were stacked in place one in front of the others, held in place simply by resting on the dials. Each sheet could be instantly removed and placed to one side. Thus, on each trial, the subject was faced with a different random arrangement of color-coded dials.

When the dials were coded with geometric shapes, each dial was centered in either a rectangle, diamond, X or + as shown in Fig. 1. During each trial, each shape appeared four times in random arrangement. As before, a series of cardboard sheets was prepared with different random arrangements on each one.

A final set of 16 cardboard sheets was prepared with the dials coded both for color and for shape. For the most part, each color and shape appeared once at each dial. A different sheet was constructed for each possible target-stimulus. For example, if the target was to be a "blue diamond," then that sheet contained four blue diamonds randomly located, a diamond in each of the other three colors, each of the other three shapes in blue (the target-color), and the remaining six dials coded by randomly choosing from the remaining three colors and shapes. This meant that 7 of the 16 dials were the target-color

The subject's eye-movements were measured with a Biometrics Inc.

The red light served simply to provide a fixation point so that the subject could focus on the plane of the array through the aperture in the shutter. He was given no instructions with respect to fixating the light.

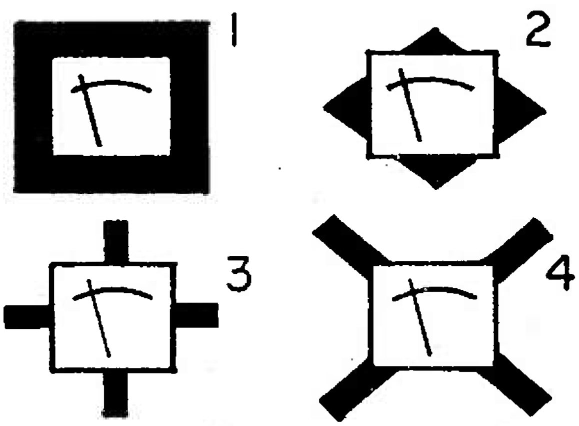

Fig. 1. The dials coded by shape. For color-coding, the rectangular outline of Dial 1 was used in various colors.

Table I. Dominant wavelength (λ), brightness contrast (C)*, and spectral purity (P) of colors used in color coding

Color	λ	C	P
Blue	482	.40	.30
Green	554	.48	.48
Yellow	574	.10	.68
Red	616	.66	.55

$$* \; C = \frac{\text{Luminance}_T - \text{Luminance}_B}{\text{Luminance}_B}$$ where T is the target and B is the background.

Eye-Movement Monitor, Model SGHV-2 and recorded on magnetic tape by a Hewlett-Packard FM Instrumentation Recorder, Model 3960. Paper records were later made with a Bolt, Beranek and Newman Plotamatic X-Y strip-chart recorder. Search-times were timed with a Lafayette Instrument Co. clock-counter, Model 54417.

Procedure

To start a trial, the experimenter selected the predetermined target-dial on his control panel. If it was a coded condition, he announced the color, or shape, or color and shape of the target-dial just before he raised the shutter which screened the subject's view of the display. If it was the uncoded condition, he simply raised the shutter and pressed the "start" button. This simultaneously (1) turned on the red light in the center of the array, (2) started the electronic timer, (3) presented a signal to the instrumentation recorder, and (4) activated every dial except the target dial, causing every indicator needle to move approximately one-tenth of the full scale deflection on the dial except one unactivated dial. The subject's task was to find as quickly as possible the dial which had not been activated. As soon as he did, he pressed a button which (1) returned every dial to zero, (2) stopped the timer, (3) turned off the red light and (4) signalled the instrumentation recorder that the trial was over. The experimenter lowered the shutter, and the subject reported the number of the target dial to ensure that he had in fact found the correct one. The coded sheet was then removed to reveal the next arrangement, and the sequence was started again with the next target-dial.

A session consisted of 64 such trials; each dial was the target four times, in random order. There were four sessions, with the four conditions counterbalanced among the four subjects. A different random order was used in every session.

Subjects

Four staff members of the Laboratory participated as subjects. Three were experienced in this type of experiment. All had 20/20 uncorrected vision and normal color vision.

RESULTS

Search-time

The mean times required to find the target-dial under the various conditions by each subject are shown in Fig. 2. Coding by shape resulted in a mean increase in search time of 1.2%. Coding by color and shape resulted in a mean decrease in search-time of 20%. Coding by color alone resulted in a mean decrease of 51.4% in search-time. Every subject found the color-coded dials in the shortest time. Three of the subjects found the dials coded by a combination of shape and color in the second shortest time and took the longest to find the uncoded target-dials. One of the subjects (JW) did especially poorly in the color-shape condition, but the general shape of his function is similar to that of the other subjects. Analysis of variance showed these differences between conditions to be reliable ($F=9.60$, $p<.003$).

A breakdown of the search-times according to specific colors and shapes is shown in Fig. 3. Three of the subjects found targets coded yellow or red faster than those coded blue or green, but one subject showed the reverse. Three subjects found the targets coded with a rectangle (called "square") or diamond faster than those coded with X or +. All did so when color was added to shape. Search-times were increased (mean increase = .77 sec) for every subject when shape was added to color but decreased (mean decrease =.51 sec) when color was added to shape.

It should be kept in mind that when the target-dial was coded only by color or by shape, there were four possible target-dials on each trial. When the dials were coded by a combination of color and shape, however, there were in addition to the four correctly coded dials three others of the same color (but different shape) and three others of the same shape (but different color). Thus, 7 of the 16 dials were of the target-color or the target-shape. If the subject were using only one of the codes, he would then have to scan 7 rather than 4 dials. This fact must be taken into consideration in evaluating the decrease in search-time when color was added to shape and the increase in search-time when shape was added to color, as noted below.

Number of fixations

The mean number of fixations required to find the target under the various conditions is given for each subject in Fig. 4. Everyone required the fewest fixations to find the color-coded dials and the next fewest to find the dials coded by both color and shape. Three subjects required the most fixations to find the uncoded dials. These differences between conditions are reliable ($F = 13.8$, $p<.001$).

The appearance of these functions is very similar to those for search-time (fig. 2). Indeed, there is a very close agreement between mean search-time

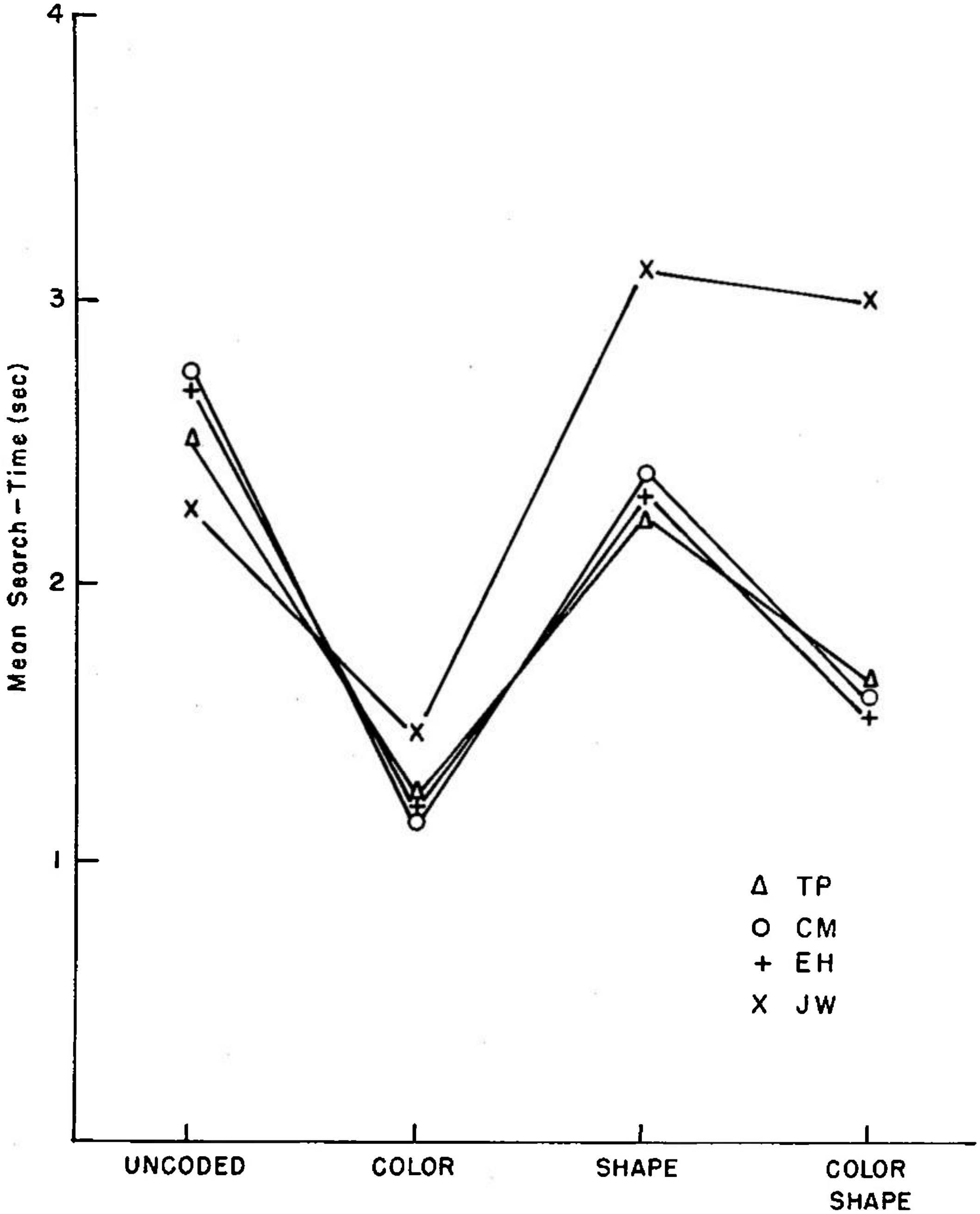

Fig. 2. Mean search-time (sec) for uncoded target-dials or for dials coded by color, shape, or a combination of color and shape.

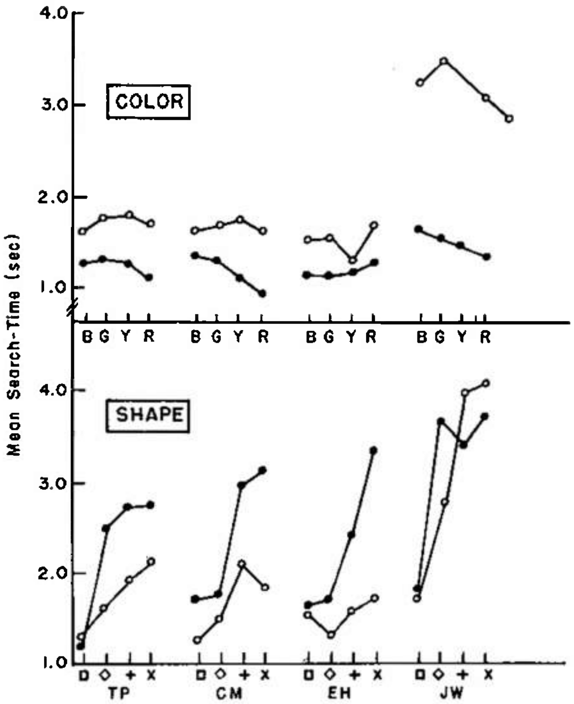

Fig. 3. Mean search-times (sec) for target-dials (top) coded by color (o) or by a combination of color and shape (o) and (bottom) coded by shape (o) or by a combination of color and shape (o).

under a given condition and mean number of fixations (r = .86).

Figure 5 shows the relationship between search-time and number of fixations for the individual subjects grouped by condition. It clearly shows the general increase in number of fixations as search-time increases. However, it reveals that there is a linear relationship between subjects only in the uncoded condition. In the coded conditions, search-time apparently depends not merely on number of fixations, but, as would be expected, on such other factors as encoding speed as well.

Non-target fixations

The effectiveness of the coding is further clarified by the pattern of fixations to non-targets. Figure 6 show the percentage of fixations on dials coded by a given color or shape (or both) as a function of the coding of the target-dial in the various conditions. For example, when the dials were coded only by color and the target was blue, 64% of the fixations were on blue dials; when the target was green, 63% of the fixations were on green dials. On the average, 69% of the fixations made in this condition were on the target-color. Color is thus an effective attention-getter. The most effective colors were red and yellow, in conformance with the results of the search-time analysis. It is interesting to note that for each target-color the percentage of fixations drops progressively as the non-target color is further removed along the spectrum from the target-color. This effect occurred in 13 of the 16 possible instances and confirms the findings of Williams.[11]

When the dials were coded by shape, the target-shape again evoked the greatest percentage of fixations, but the mean percentage was only 41% of the total. Shape is thus a less effective coding device than color. The most effective shape was the square, followed by the diamond. The X and + were much less effective, each evoking only about 35% of the fixations. These

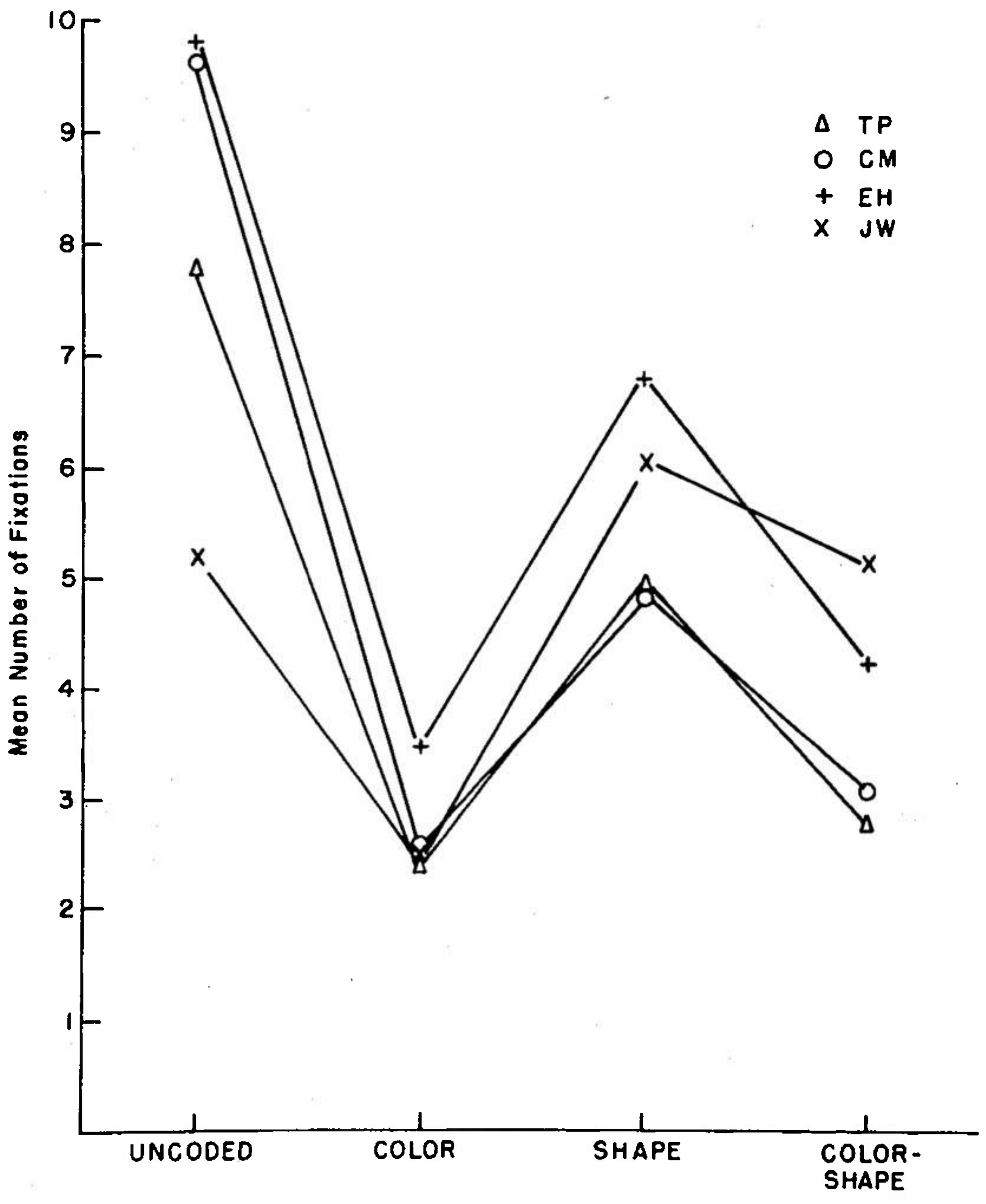

Figure 4. Mean number of fixations required to find the target for each subject under the various conditions.

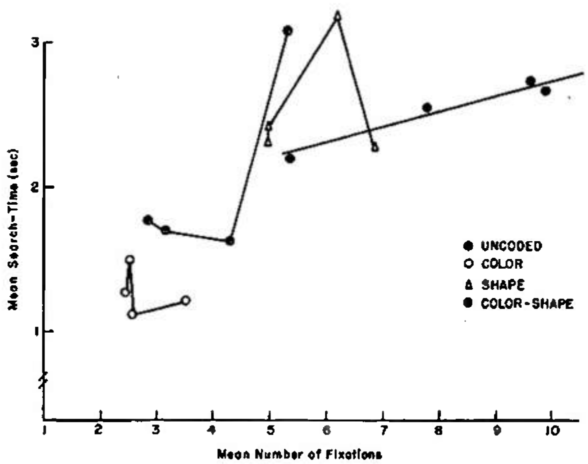

Fig. 5. Mean search-times as a function of number of fixations for each subject in the various conditions.

results are again in agreement with the search-time data.

An analysis of the fixations in the color-shape condition is given in Table II. It shows that the subjects were responding to both color and shape. Disregarding the correct shape, 84% of the non-target fixations were made to the correct color; conversely, 70% of the non-target fixations were made to the correct shape.* Although shape is thus a less effective code, the subjects were responding rather effectively to it. Restricting the correct fixation to both color and shape, 53% of the non-target fixations were correct.

**These high percentages in the color-shape condition are due in part to the higher proportion of relevant dials, as noted above.*

Fixation duration

We have calculated, first of all, a rough estimate of the mean fixation-duration: the mean time spent in search as a function of the number of dials fixated. On some trials, of course, the subject found the target-dial on the first fixation; on other trials, various numbers of fixations were needed. Calculated this way, the measure neglects the time taken by such things as saccades, which in reading generally take up much less than 10% of the total time.[12] We will refer to this measure as "estimated fixation-time."

When estimated fixation-time is plotted against the number of fixations on a given trial, a set of characteristic curves emerges. These are shown in Fig. 7. If the target-dial was the first one fixated, the total time for that fixation was high. This of course includes the initial reaction-time, the time needed to encode the target-stimulus, as well as the time needed to identify the target as the correct one and to respond to it. As the number of fixations during a trial increased, the mean time per fixation decreased sharply for the first four or five additional fixations. But as the number of fixations increased further, a plateau was reached and the mean time per fixation tended to remain constant or to decrease very slowly. When color was involved, however, the final plateau took longer to reach; in fact, it does not appear to have been reached in most cases.

Tables III and IV give the mean durations of the one-fixation trials as well as the mean durations of the seven-fixations trials. The latter, which are

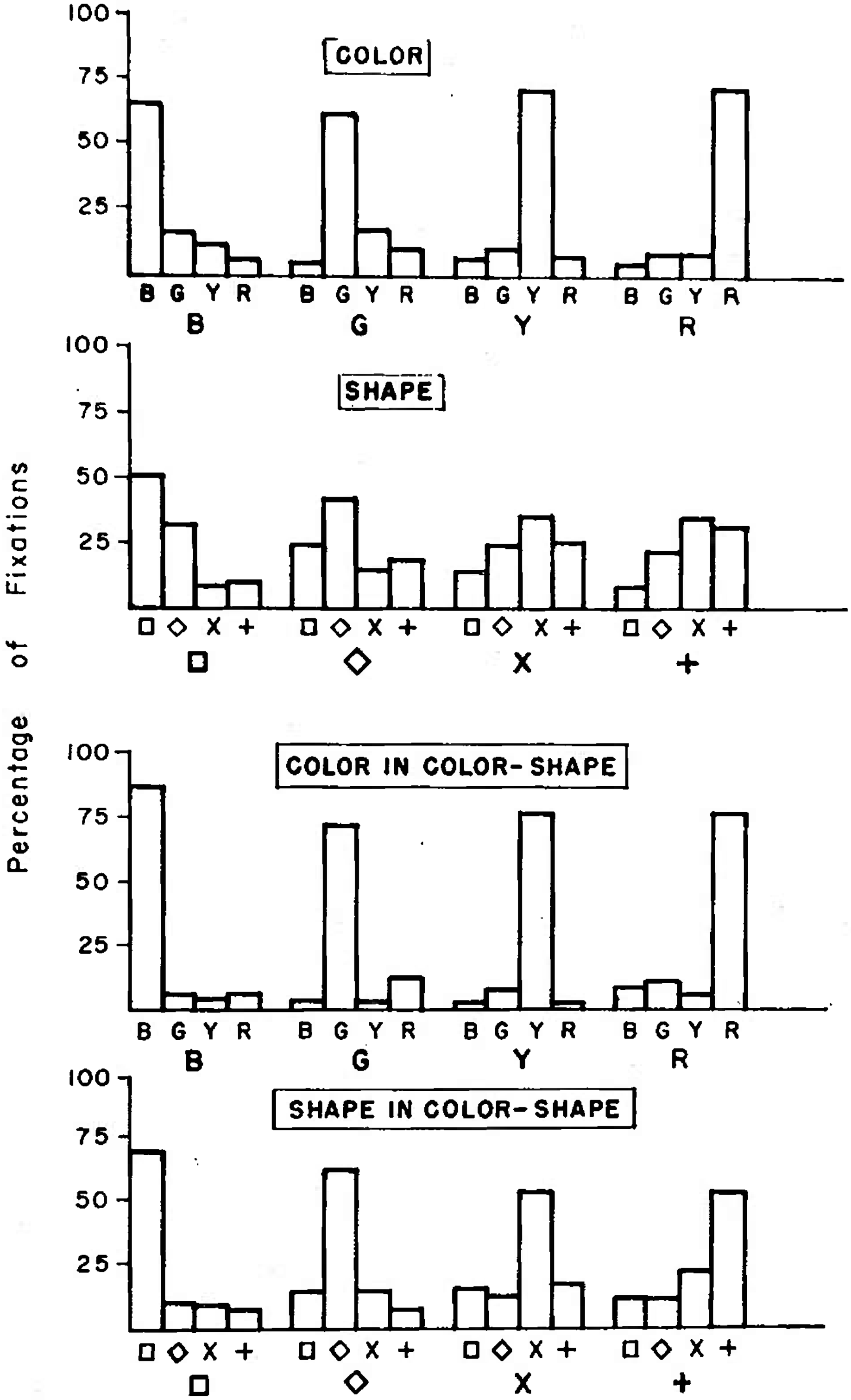

Fig. 6. Percentage of fixations on dials coded a given color or shape as a function of coding of target-dial. The target is indicated by the larger symbols under each section of each graph.

Table II. Percentage of total fixations on the various stimuli when targets were identified by both color and shape.

Target		B	G	Y	R	Mean	Target		□	◇	X	+	Mean
□	□	89	64	82	78	78	B	B	97	88	85	81	88
	◇	3	14	8	10	9		G	3	4	3	6	4
	X	0	14	4	4	6		Y	0	4	6	3	3
	+	8	8	8	6	8		R	0	4	6	10	5
◇	□	8	10	9	12	10	G	B	8	3	6	2	5
	◇	76	71	74	73	73		G	82	84	79	76	80
	X	8	9	14	10	10		Y	2	5	6	5	4
	+	8	10	3	5	6		R	8	8	9	17	10
X	□	12	14	8	12	12	Y	B	0	0	10	5	4
	◇	10	11	10	11	10		G	8	7	2	10	7
	X	61	61	66	62	62		Y	92	84	85	80	85
	+	17	14	16	15	16		R	0	9	3	5	4
+	□	9	9	10	7	9	R	B	0	8	5	9	6
	◇	9	14	6	7	9		G	8	6	8	6	7
	X	18	15	18	18	17		Y	4	3	3	6	4
	+	64	62	66	68	65		R	88	83	84	79	84

usually on the plateau, were chosen because they were the last point which appeared in every curve. Table III shows that the mean durations for the one-fixation trials, although somewhat shorter for color, are approximately the same for all the conditions ($F = 2.20$, $p > .15$). When the asymptotic values are compared (Table IV), the mean duration per fixation is the same for the color-coded and uncoded dials, but much higher for the shape-coded and color-shape dials ($F = 12.76$, $p < .001$).

This analysis reveals interesting differences between subjects and conditions, but it does not give a measure of true fixation-time, how long it took the subject to respond to the target-dial, and provides no explanation for the differences between the curves.

We have therefore obtained a measure of the true reaction time, the actual fixation-duration during the scanning, and the duration of the final target-fixation for each subject. Eight trials under each condition to a random selection of target-dials were printed on a strip-chart recorder. The mean values are given in Table V. The analysis was accurate to about 25 msec.

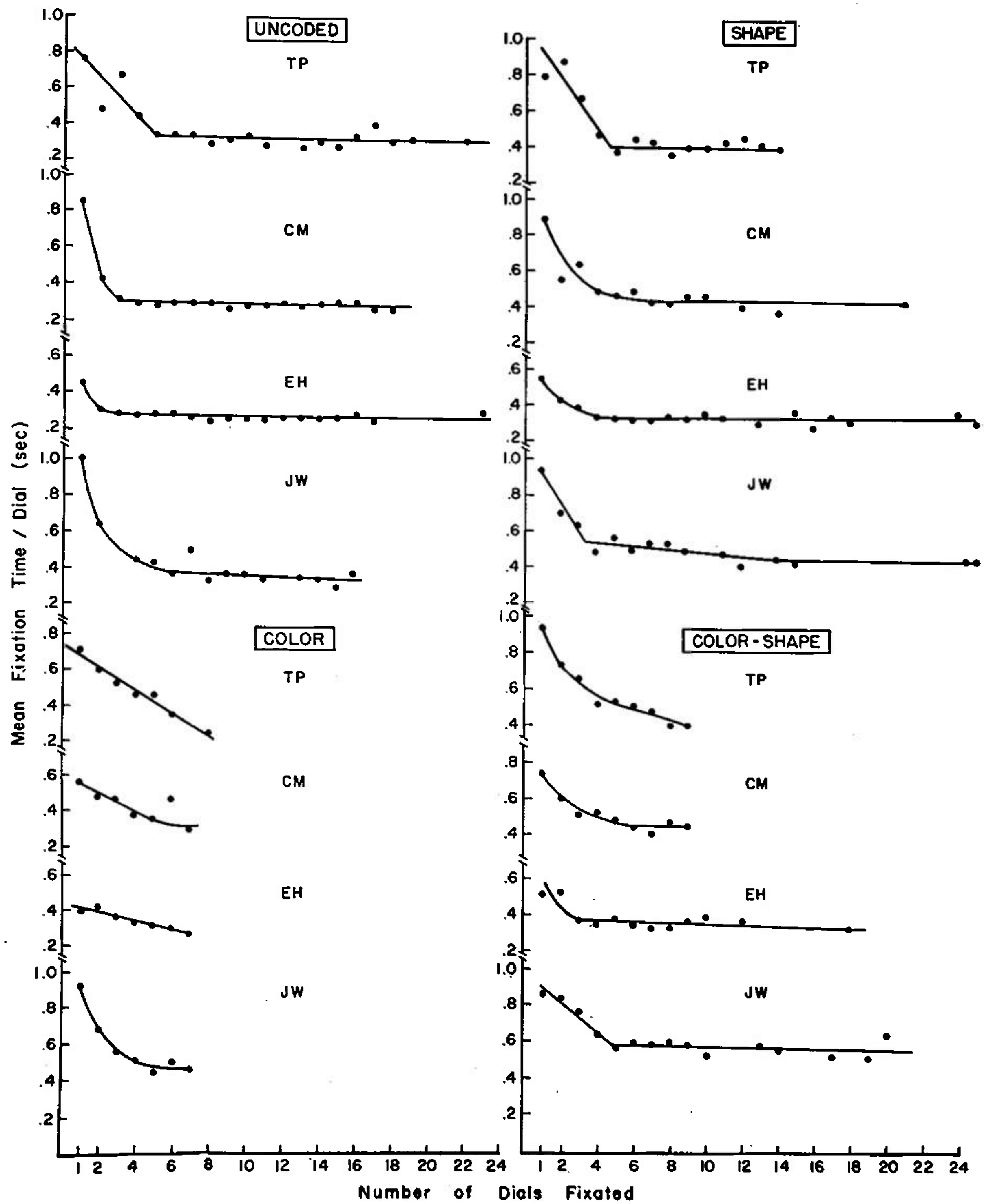

Fig. 7. Estimated fixation time (see text) as a function of the number of dials fixated during a given trial for each subject in the various conditions.

Table III. Mean estimated fixation-time (sec) for 1-fixation trials

Subject	Uncoded	Color	Shape	Color-Shape
TP	.76	.71	.79	.94
CM	.85	.56	.89	.74
EH	.46	.40	.54	.51
JW	1.01	.92	.94	.86
Mean	.77	.65	.79	.76

Table IV. Mean estimated fixation-time (sec) for 7-fixation trials

Subject	Uncoded	Color	Shape	Color-Shape
TP	.33	.29	.40	.45
CM	.29	.21	.44	.44
EH	.28	.28	.33	.36
JW	.38	.45	.50	.57
Mean	.32	.31	.42	.46

There were considerable differences in the time the subjects took to begin searching once the trial had begun ($F = 13.00$, $p < .001$), but the differences between subjects for fixation duration and duration of final fixation were not reliably different. Initial reaction-time was not reliably different between conditions, although three subjects had longer reaction times in the uncoded condition.

There were reliable differences in fixation-duration between conditions ($F = 4.98$, $p < .03$). Fixation-duration was much shorter in the uncoded condition where only the dial reading had to be processed. There were no reliable differences in duration of the final fixation between conditions, although mean duration was again shorter in the uncoded condition.

We have also measured fixation duration for each fixation in the sequence of fixations during a given trial. There was no evidence of a decrease in fixation duration during the course of the

Table V. Temporal analysis of eye-movements (sec)

S	Uncoded	Color	Shape	Color-Shape	Mean
Initial Reaction-Time					
TP	.332	.312	.328	.266	.310
CM	.114	.137	.219	.256	.182
EH	.246	.082	.096	.085	.127
JW	.439	.412	.308	.342	.375
Mean	.283	.236	.238	.237	
Fixation Duration*					
TP	.185	.190	.188	.224	.197
CM	.128	.240	.200	.207	.194
EH	.155	.192	.182	.235	.191
JW	.199	.223	.248	.240	.228
Mean	.167	.211	.205	.226	
* Not including final fixation on target					
Duration of Final Fixation					
TP	.306	.257	.411	.484	.364
CM	.183	.341	.313	.406	.311
EH	.254	.358	.337	.336	.321
JW	.345	.266	.279	.258	.287
Mean	.272	.306	.335	.371	

trial, as reported by Llewellyn-Thomas and Lansdown[13] for observers scrutinizing X-ray plates.

Comparison of various measures

We may next compare the consistency of the various measures. We would expect a short search-time to be associated with a small number of fixations, a large percentage of one-fixation trials, a low percentage of non-target fixations and a short fixation duration. Table VI shows that, except for those measures relating to fixation-duration,

Table VI. Comparison of the various measures in the different conditions

Measure	Uncoded	Color	Shape	Color-Shape
Mean search-time (sec)	2.56	1.26	2.54	2.04
Mean number of fixations	8.13	2.76	5.75	3.90
Number of one-fixation trials	8.5	23.0	13.8	18.0
Mean "fixation duration" (sec)	0.31	0.31	0.42	0.46
Percent non-target fixations	--	.31	.59	.48
Duration of one-fixation trials (sec)	0.77	0.65	0.79	0.76
True fixation duration (sec)	0.17	0.21	0.21	0.23
Final Fixation time (sec)	0.27	0.31	0.34	0.37

they are consistent and indicate that color was the most effective code, shape was least effective and the combination of color and shape was intermediate.

The same comparison is made for the individual colors and shapes in those two conditions in Table VII. Once again, there was good consistency between all the measures except fixation-duration for both color and shape. Red and yellow were more effective than blue and green. The square was the most effective shape and the + was generally the worst.

Individual performance

The question next arises as to the degree to which these various measures contribute to an individual's search-time. The similarity between the curves of search-time and number of fixations (Figs. 2 and 4) immediately suggests a close relationship between these two variables. We have therefore replotted in Fig. VIII the data in Fig. 5, grouping the results in the four conditions for each subject. The two measures are clearly related for every subject; the correlations range from .88 to .97. Thus a subject's search-time from one condition to another is explained to a great extent simply by the number of fixations he had to make. However, as Fig. 5 shows, it does not explain how he will compare with other observers in the coded conditions.

To determine if these individual differences can be attributed to the other variables of reaction-time, fixation-duration, and the time taken by the final fixation, these data were subjected to analyses of regression and covariance, in which an attempt was made to control for differences in an individual's performance due to the varying conditions. Where the statistical assumptions were met, these analyses showed that there were consistent (positive)

Table VII. Comparison of the various experimental measures in the color and shape coded conditions

Measure	Color Coded				Shape Coded			
	Blue	Green	Yellow	Red	□	◇	X	+
Mean search time (sec)	1.28	1.34	1.22	1.20	1.61	2.43	3.24	2.88
Mean fixations	2.89	2.94	2.45	2.61	3.08	6.92	8.12	8.69
One-fixation trials	5.2	5.8	6.2	6.2	4.5	4.0	3.75	2.25
Mean "fixation duration" (sec)	.53	.54	.55	.58	.55	.55	.54	.52
True mean fixation duration (sec)	.22	.19	.23	.19	.20	.22	.22	.20
Percent non-target fixations	.36	.37	.28	.25	.49	.58	.67	.69
Duration of one-fixation trials (sec)	.69	.70	.69	.73	.79	.85	.97	.74
Final fixation-duration (sec)	.36	.30	.29	.27	.34	.39	.35	.26

correlations for all subjects between search-time and these three variables only in the uncoded condition. Only two other correlations held for all conditions: between search-time and fixation-duration (.50) for TP and between search-time and reaction time for JW (.64). Thus, although the reaction-times of both EH and JW were reliably different between conditions, only for JW were these differences reflected in search-times.

Location of target

Knowing that subjects were responding both to color and shape leads to the question of the effectiveness of these identifiers at various retinal position. Are there differences in the relative effectiveness at different parts of the visual field? To answer this question, we have compared search-times in the various conditions for targets in the center of the array (the four dials surrounding the center light), corners of the array (the dials at each corner), and periphery (the remaining 8 dials). The mean search times in the various conditions are plotted for these three sectors of the array in Fig. 9. Mean search-time is clearly best in the center, poorer in the periphery and worst for the corners. These differences are reliable ($F = 4.11$, $p < .05$). Indeed, almost invariably, differences between any two types of coding increase as the target-dials are located farther from the center of the array.

It is also clear from Fig. 9 that the increase in mean search-time as the

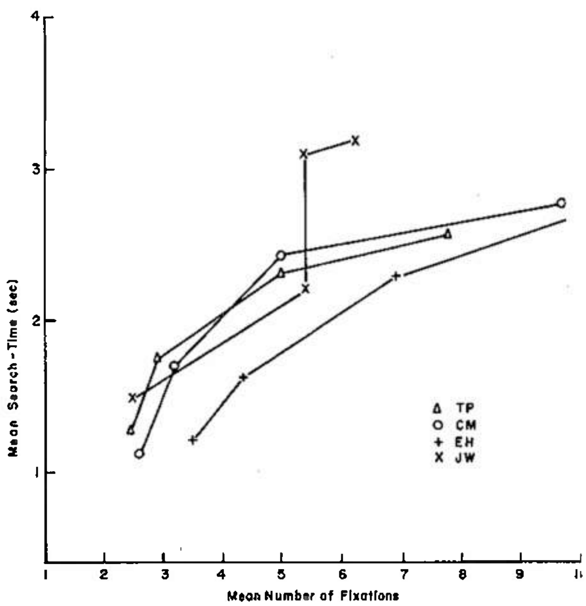

Fig. 8. Mean search-time as a function of the number of fixations for each subject in the various conditions.

target is moved from the center to the corners is much the same no matter what the coding. It is obvious that the relative increase in search-time is no greater for shape, for example, that for color.

Scanning patterns

In general, the subjects did not exhibit a characteristic, reliable, scan-path during their searches. Of the total number of 16 sessions, there was a systematic scan-path in only two. Two subjects exhibited a reliable pattern of search during the uncoded conditions. During the other conditions, all subjects searched randomly; their scanning was governed essentially by the random arrangement of the stimuli.

An indication of the degree to which a search-pattern was systematic is given by the ratio of the number of fixations to the dial which was looked at most often to the number of fixations to the dial which was looked at least. If the search is completely random, this ratio should be unity. A higher ratio indicates a less random search. Table VIII shows that only subjects CM and EH carried on a systematic search and only during the uncoded condition. (JW's high ratio during the color condition resulted from a tendency to avoid scanning the lower row of dials.) These differences are not statistically reliable, but it may be noted that the ratios are lowest in the shape condition for every subject.

Although it is clear that most of the scanning was not systematic, it is of interest to relate the regularity of scanning to the speed with which the target-dial was found. We have calculated the correlations both for each condition pooled over subjects and for each subject pooled over conditions. Most of the correlations are positive, but they are not high enough or consistent enough to conclude that there is a relationship.

DISCUSSION

Scan-paths

This study was concerned primarily with two sets of questions. The first was whether or not individuals have characteristic scan-paths and do they

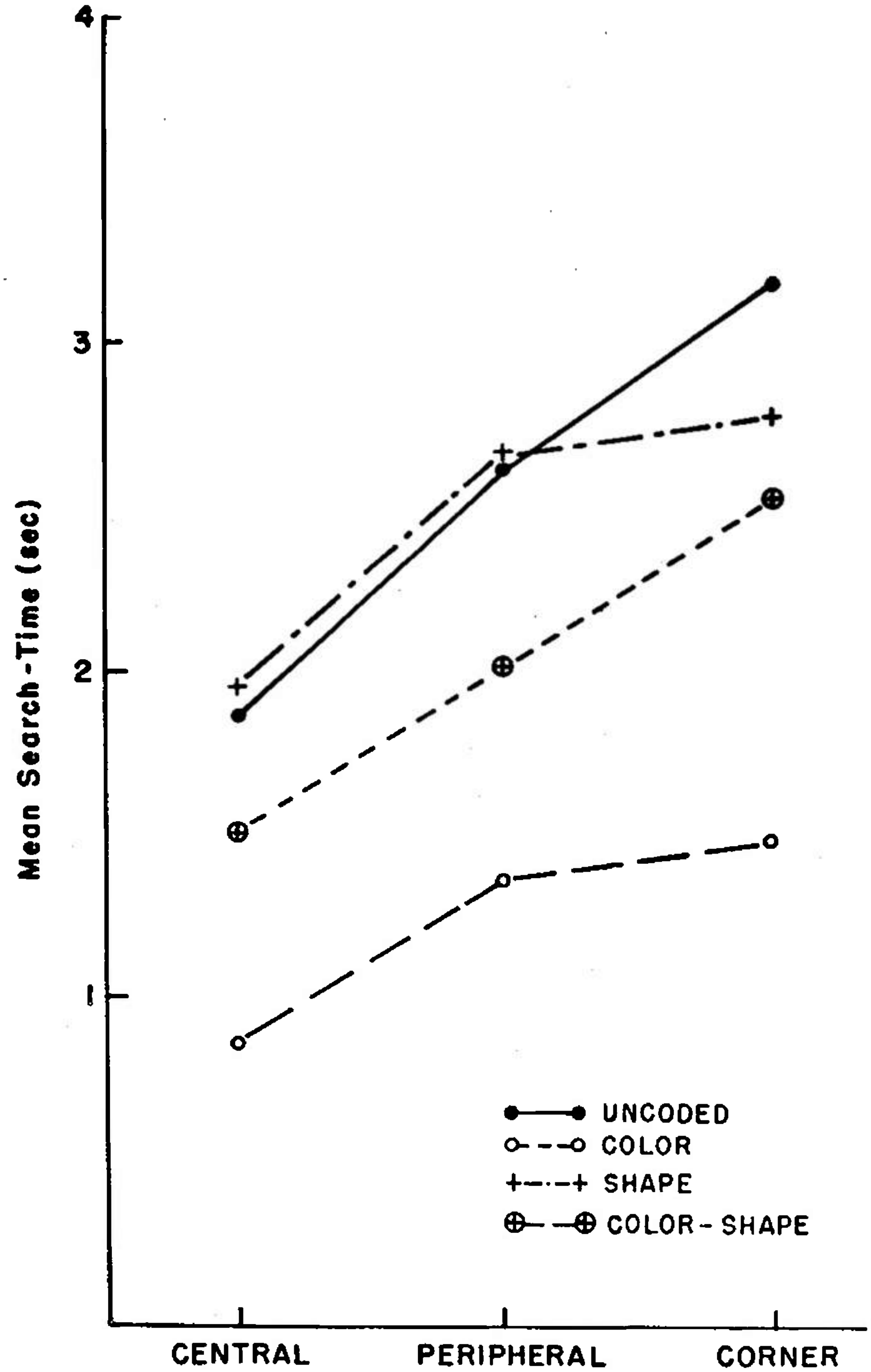

Fig. 9. Mean search-time for targets situated in various parts of the array under the various conditions.

Table VIII. Ratios of largest number of fixations on a dial to the smallest number of fixations on a dial during each condition for each subject

Subject	Uncoded	Color	Shape	Color-Shape
TP	1.65	1.86	1.67	3.80
CM	10.83	4.75	2.89	4.80
EH	9.00	3.50	1.85	2.30
JW	3.44	7.00	2.69	2.83
Mean	6.23	4.28	2.28	3.43

relate to efficiency of performance. As a general rule, our subjects did not exhibit reliable patterns of scanning as they searched the array of dials for the target. Only when the dials were uncoded did two of the subjects search the array systematically* but we did not discern evidence of a reliable scan-path in any other condition. Scanning in this task was different, therefore, from that reported during repeated perusal of patterns by Notion and Stark[5] and from that reported by Gould and Peeples[6] for subjects matching eight figures to a central standard. The latter noted that "although different Ss scanned patterns in different orders, each S generally used the same scan pattern throughout the experiment" (p.54); their experiment was most comparable, of course, to our uncoded condition. It appears therefore, that whether a subject scans systematically or not depends on the particular task or conditions.

In addition to the systematic nature of the scan, one subject also exhibited this reliable characteristic: she scanned vertically, rather than horizontally, and, almost invariably, when she came to the lowest dial in the first column refixated the dial above it before moving on the second column. Another characteristic of the two fastest scanners (CM and EH) was that they typically went past the target-dial and had to return. This indicates, of course, that processing of the target-stimulus had begun during the brief fixation, continued while the observer moved on, and was completed during the subsequent fixation.

There was no indication that systematic scanning was related to speed of target detection.

Effect of coding

The second set of questions concerned the effect of the stimulus-variables. These results show that search-time was considerably reduced for three of the subjects when the dials were coded. Color was the most effective coding, as several investigators have found before.[14–18] For out particular stimuli (Table I), red and yellow were more effective colors for every subject in terms of search-time, fixations, one-fixation trials, and non-target fixations. Interestingly, Williams[11] found that the largest percentage of fixations was to orange targets. In addition, mean estimated fixation duration and mean duration of final fixations were shorter for red and yellow for three subjects. Green was typically the worst color: Table II shows that in the color-shape condition, for example, it attracted the smallest percentage of total fixations; in the color condition it produced the longest reaction-times, the largest number of fixations, the largest number of non-target fixations and the third lowest number of one-fixation trials. These results conform to those of a large number of studies on the visibility of colors in the periphery which show that green has the smallest area of retinal sensitivity.[19-20] Visibility of green has been reported to deteriorate relatively rapidly under adverse viewing conditions.[21-22]

Although the differences are small, it is interesting that we also found a gradient of decreasing number of fixations to colors further removed along the spectrum from the target-color (when coded by color alone) as did Williams.[11]

Shape was a much less effective coding than color. Even at its best (the square), it resulted in increased mean search-time, fixations, non-target fixations and fewer one-fixation trials. The duration of the one-fixation trials was longer for shape than color, presumably because of the increased time needed to encode the target-stimulus. However, duration of the subsequent fixations was the same in both conditions. There were much greater differences between the various shapes than between the different colors for virtually every measure. When shape and color were both used, performance measures were typically intermediate those for color or shape alone. This suggests that subjects were using only color as the code in their search but were distracted to some extent by the shapes. Williams[11] concluded that when targets were specified by more than one characteristic, subjects tended to ignore the less effective one. On the other hand, Stone[17] found that all subjects were slowed by the presence of irrelevant shape information and unable to ignore it.

To determine if our subjects were able to utilize the available shape information, a correction must be made for the different number of relevant dials in the different conditions: In the color and shape conditions, only four dials were the target-color or the target-shape. In the color-shape condition, 7 dials were either the correct color or the correct shape. Therefore, subjects using only one of the codes should have been handicapped. Assuming for simplicity that the decrease in effectiveness is a linear function of the additional dials to be scanned, we would expect search-time to increase from 1.26 sec (see Table VII) to 2.22 sec. It increased only to 2.04 sec. Similarly, number of fixations should have increased to 4.86 but in fact increased only to 3.90. The percentage of non-target fixations increased only to 46% rather than 55%. And the percentage of one-fixation trials which should have decreased from 23 to 13% decreased only to 18%. We conclude, therefore, that the subjects were in fact using both characteristics, and that if the number of relevant dials were the same in both the color and color-shape conditions, it is possible that search-times would have been shorter in the color-shape condition.

Table I breaks down the fixations in the color-shape condition according to both codes. It is quite clear that the subjects' fixations were governed by both. For example, when the target was a square, 78% of the fixations were on the square, irrespective of the target-color. Even when the target was an X, 62% of the fixations were on the correct shape. What is not completely clear is whether the double coding was always a help. Color added to shape certainly improved performance, but the effects of shape added to color are not certain.

The fact that the subjects fixated the correct shape more often than not indicates that they could process shapes non-focally to a large extent. For the stimuli used in this experiment, the rate of increase in search-time as the targets were situated more peripherally was not greater for shape than color (Fig. 7). The difference in effectiveness of color and shape was present foveally and remained constant at the other retinal locations.

These findings are somewhat at variance with the conclusions of Ellis and Chase[23] that most shapes (except for gross attributes) require focused attention. Our subjects' performance was not dramatically worse with the shapes used in this study than with color. The percentage of correct fixations was of course less for shape than color, but there seems to be little room for doubt that shape was being processed non-focally. Stone[24] has also concluded that some information is gained about a peripheral stimulus and that as the stimulus location was more peripheral, response latency increased. Gould[26] also reported that some peripheral encoding occurs and that there is a linear relation between fixation duration and the separation from the next target. Peeke and Stone[27] investigated the problem in some detail and concluded that the differences in response latencies to color and shape are increased as the stimuli are more peripheral, with the advantage for color.

The present results also show that the differences in search-time between any two conditions (except for shape and color-shape) typically increase as the stimuli are farther removed from the central fixation-point, but, as noted above, the rate of increase of search-time was not greater for shape that color. This is perhaps the biggest discrepancy between these results and previous ones. Peeke and Stone[27] reported that when two stimuli are presented simultaneously and the subject is required to make a judgment about them, response latencies are shorter when the stimulus variable is color rather than shape. On the other hand, when the two stimuli are presented one after the other, response latencies are shorter for shape. It could be argued that in the present study, the stimuli were presented sequentially: first the target was identified to the subject, after which he searched for a match to this information. Yet we did not find shorter latencies to shape than to color.

The explanation of why our results were not superior for shape may be that color can be processed peripherally better than shape. Peeke and Stone's display subtended 24° visual angle, less than half of our display. Shape may thus have had a greater advantage in their experiment than in ours. But we believe that the explanation of all these discrepancies must lie in the fact that the discrimination of both shape and color deteriorates in the periphery. Indeed, as viewing conditions worsen in any way, there are regular changes in the perception of color and in the confusions that arise between colors.[28] It would not be difficult to choose colors which are harder to discriminate than a set of suitably selected shapes. But there is no a priori way to equate differences in discriminability of colors compared to that of shapes. It must be done empirically for both the colors and shapes involved. The many reports that color-coding is better than shape-coding may often simply reflect the specific stimuli used.

Fixation duration

The failure of fixation-duration to conform to the other measures is noteworthy. Gould and Dill[29] reported the same finding and wondered if it indicated that fixation-duration was not an appropriate measure of performance. The present results indicate that fixation-duration is not an important predictor of efficiency of search. It accounts at most for only a small fraction of the variance. The results therefore conform with those found in studies of reading. Tinker[12] has reported that fixation-duration is a poor predictor of reading proficiency, in contrast with number of fixations which is fairly valid as a measure of speed of reading proficiency.

Despite its lack of consistency with the other measures, fixation-duration is apparently indicative of at least some of the cognitive processes occurring. It is, for example, reliably less for uncoded dials and tends to be longer for dials coded by color or shape, and thus presumably reflects encoding time. Similarly, Tinker reports that fixation duration is about 220 msec for easy prose, about 236 msec for scientific prose, and even longer for reading objective test questions.

Peeke and Stone[27] reported that color and shape are processed by most subjects at the same speed. Although we did not find the same search-time, fixation duration was the same in both conditions (Table V), and calls to mind the results of experiments based on information-processing theory which show that shape[30] as well as color[31-32] are characteristics which are encoded very early in the perceptual process.

A final question has to do with the relationship between speed of target-detection and speed of scanning. Gould and Dill[29] reported that fast scanners tend to make fewer fixations of shorter duration. Mackworth[33], on the other hand, has reported that faster scanners make more fixations of shorter duration.

Defining a fast scanner as one who finds the target quickly (as Gould and Dill did), we found a relationship between search-time and number of fixations only for the uncoded condition: subjects who found the target quickly made few fixations. There was no relationship in the other conditions (Fig. 5). When, however, the subjects' performances were averaged over conditions, the one who had the fastest mean search-time had the most fixations.

On the other hand, fixation-duration was quite different. In the uncoded condition, long fixation-durations were associated with short search-times; in the other conditions, the opposite was true (Fig. 8). The latter seems reasonable; we have no explanation for the former.

CONCLUSIONS

Search-time was considerably reduced when the target-stimuli were coded. This reduction in search-time was manifested primarily by a reduction in the number of fixations required, although other measures were also positively related to search-time. Thus, the effectiveness of a code depended primarily on its ability to attract fixations and only to a small extent on the time needed to process the stimulus after fixation.

Color appeared to be the most effective code. There are indications, however, that a combination of color and shape was even more effective if differences in the probability of target-detection between the two conditions are taken into account.

The combination may have been more effective because shape was also being processed non-focally. Stimulus-location was important - search-time increased as the target was located more peripherally - but the rate of increase was approximately the same for shape as for color. This suggests that shapes, if properly chosen, may be as effective a coding system as solor.

Subjects did not exhibit a reliable, characteristic scan-path, except for two subjects in the uncoded condition. And there was no indication that one method of scanning was superior to another.

Fixation-duration did not correlate with search-time as did several other measures, but it did give some indication of cognitive functioning; it was, for example, longer in the color-shape condition than in the uncoded condition.

Although it turned out that the effects of coding the stimuli can be predicted with a high degree of accuracy, the reasons why one subject is a faster scanner than another in a given condition are still not clear. Individual differences in scanning ability are presumably dependent on many perceptual and cognitive aspects whose importance probably varies among subjects.

These findings do not suggest that monitoring efficiency can be improved by training observers to follow a given scan-path in their monitoring. Indeed, they suggest rather that effeciency in finding targets may well be impaired if an individual's eye-movements patterns are interfered with. But the results also reaffirm that coding is an effective way of reducing search-time; individuals can keep and use two separate codes simultaneously in searching for a target; and the gross stimulus characteristics used in this study can be processed to a considerable degree in the periphery of the visual field.

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13. ABSTRACT

Eye-movements and search-time of four subjects were studied as they searched for a target-dial in a 4 x 4 array of dials which were differentiated either by (1) color, (2) shape, (3) a combination of color and shape, or (4) were uncoded. Search-time varied reliably between conditions: it was generally shortest in the color-condition, followed by color-shape, shape, and the uncoded condition. Subjects were capable of using both shape and color simultaneously. There was no difference in ratios of increase of search-time for color and shape as the target was situated more peripherally, and there was evidence that shapes, if properly chosen, might be as effective a coding device as color. Search-time was strongly associated with the average number of fixations required for target-detection but not with other measures of eye-movements. Subjects did not exhibit a reliable or characteristic scan-path, and method of scanning did not relate to search-time.

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